Sensitivity: General

Characterisation of Food Waste Derived Biofertiliser

DBPAS 10

Prepared for Bioenergy Association of New Zealand
Prepared by Beca Limited

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make everyday better.

Contents

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Glossary

Anaerobic digestion (AD)	Decomposition of organic materials by microbial species in the absence of oxygen.
Biofertiliser	Fertiliser produced from organic material, in this case, food waste digestate.
Biogas	Gaseous fuel, usually methane, produced by the anaerobic digestion of organic matter.
BANZ	Bioenergy Association of New Zealand
Carbon to Nitrogen Ratio (C/N)	The amount of carbon relative to the amount of nitrogen present. Usually expressed as a single number.
Circular Economy	An economic system based on the reuse and regeneration of materials or products, especially as a means of continuing production in a sustainable or environmentally friendly way.
DBPAS	Digestate Biofertiliser Producer Certification Scheme
Digestate	Material remaining after the extraction anaerobic digestion of energy in the form of biogas, but in which all other constituents used are retained.
Emerging contaminant	Synthetic or naturally occurring chemicals or any microorganisms that are not commonly monitored in the environment but have the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects.
Feedstock	Raw material supplied to a machine or processing plant.
Legacy Contaminant	Persistent materials in the environment that were created through a polluting industry or process that have polluting effects after the process has finished.
Mesophilic digestion	Anaerobic digester that operates in temperatures between 20°C and 40°C.
Nitrification	Oxidation of ammonium to nitrites and then to nitrates by bacteria.
PFAS	Per- and polyfluorinated substances.
Source Separated Food Waste	Segregation of compostable materials from other waste.
Thermophilic digestion	Anaerobic digester that operates in temperatures between 50°C and 70°C.
Volatile Solids	Fraction of total solids that is comprised primarily of organic matter.
Volatilisation	Transfer of a chemical as a gas through the soil/air or liquid/air interface.

1 Introduction

Beca Limited (Beca) has been engaged by the Bioenergy Association of New Zealand (BANZ) to prepare a literature review of the characterisation of biofertiliser, including aspects related to:

- A description of food waste feedstock
- Benefits for use on agricultural land, drawn from peer reviewed research and comparisons to conventional fertilisers.
- Information on the New Zealand accreditation schemes and a discussion of risks and their management related to contaminants.
- A discussion of practical application and storage of biofertiliser.
- A discussion of social considerations for the use of biofertilser in New Zealand.

Digestate considered includes the liquid, sludge, and dry forms.

This literature review has drawn on local and international sources of scientific research, international certification schemes, and where appropriate or necessary, other forms of information such as technical publications or guidance from producers of biofertiliser. The review will aid BANZ in producing high quality, clear information sources for users and producers of biofertiliser.

This document also highlights areas that require further study and investigation to support the implementation of an accreditation scheme that suits the unique needs and requirements of Aotearoa New Zealand.

2 Biogas and Digestate

Biogas is produced via anaerobic digestion. Anaerobic digestion is the process in which organic matter is broken down by bacteria in the absence of oxygen. This process may either be mesophilic (run at a temperature range of 20-40°C) or thermophilic (run at a temperature range of 40-70°C). Organic waste is a typical source material (feedstock) for anaerobic digestion, typically a low value material with no further use. Crops may also be grown specifically for the purpose of producing biogas.

Often, low value waste materials are useful as the feedstock or biomass as they help solve waste issues. The feedstock is generally high in volatile components (which is advantageous for biogas production) and contains a range of nutrients and trace minerals. Examples of feedstock are listed below:

- Solids or skimmed liquid waste from wastewater treatment plants;
- Meat waste from abattoirs;
- Commercial or household food;
  - Segregated household food waste (“source separated”) as a feedstock is the focus of this review. Use of source separated food waste is appropriate to produce biogas and digestate as less effort is required at the digestion plant to remove unsuitable materials or large contaminants.
- Agricultural residue crops;
- Fat or oil waste;
- Woody waste and other agricultural residues.

The by-product of biogas production is called digestate, defined as:

‘Material remaining after the extraction (anaerobic digestion, or AD) of energy in the form of hydrocarbon compounds (biogas), but in which all other constituents used are retained’ (Al Seadi et al., 2013; Wilken et al., 2018)’.

Internationally digestate is seen as a product with circular, environmental, and economic value as it can be processed into a fertiliser. In New Zealand this is only occurring on a minor scale; with climate change crisis and commitments to the Zero Carbon Amendment Act (2019) there will be a shift away from natural gas and therefore there will be the opportunity for greater biogas, and digestate production.

On this basis, an accreditation scheme for producers has been developed by BANZ. The schemes will allow the production of reliable and safe certified biofertilisers as they come to market, distinguishable from raw, uncertified digestate. Digestate that is not from an accredited AD producer may contain unknown contaminants, or contaminants above specified limits, and thus cause environmental harm and upset farm nutrient balances among other issues (see **Section 4** for more details).

2.1 The Waste Hierarchy and Food Waste Feedstock

To produce biogas and therefore digestate, it's important to understand feedstock – in this case food waste - composition.

There is no New Zealand data available on the composition of food waste, likely because focus is put on the prevention of food waste rather than how it could be utilised as a product (Ministry for the Environment, 2023b)

The food waste recovery hierarchy (Figure 1) puts energy and nutrient recovery (under which digestate falls) low on the agenda, which suggests that new publicly funded research initiatives will likely be focussed on prevention and redistribution levels. This hinders the exploration of food waste to fertiliser opportunities in New Zealand.

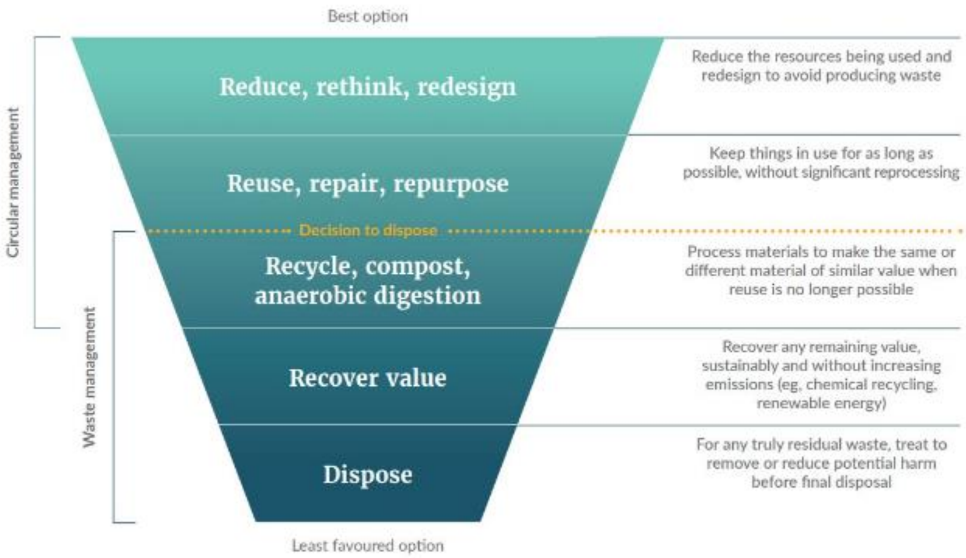

Figure 1: Food waste hierarchy. Reproduced Figure 2 from Te rautaki para, waste strategy: Getting rid of waste for a circular Aotearoa New Zealand (Ministry for the Environment, 2023).

International studies investigating the composition of household waste in the UK, showed that household waste may comprise of almost 50% fruit and vegetable waste, 4.7% meat and fish, 0.6% dairy and 0.4% contamination as shown in Figure 2 (Banks et al., 2018). The purpose of the compositional analysis was to create a feedstock recipe for optimal AD, and to understand how much of household food waste might contain material unsuitable for AD.

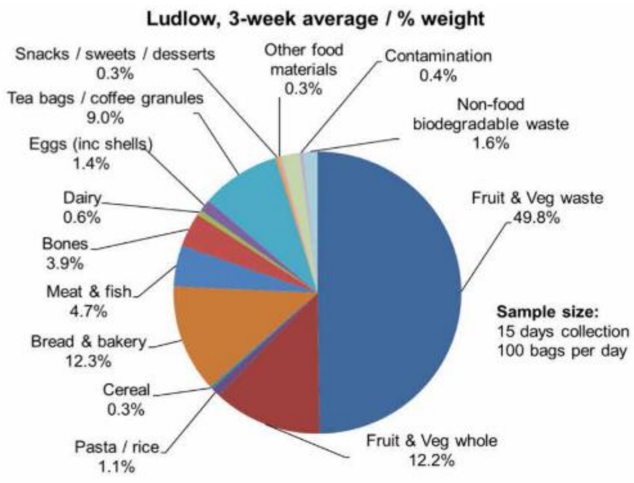

Figure 2: Reproduced food waste composition from one United Kingdom collection scheme (Figure 5, Banks et.al. 2018)

The research suggested that some variability between households is expected, however the general makeup will likely be consistent enough that digestate quality can be managed sufficiently during the AD process.

Other forms of food waste that have potential as a feedstock and would be accepted under the BANZ scheme are:

- Commercial organic waste (e.g. restaurants, catering facilities)
- Food markets, butchers, and bakers.
- Schools and workplaces.

For the producers of biogas and digestate, it is essential to understand feedstock composition (both physical and chemical properties, to improve the AD process and therefore produce a consistent and high quality digestate (Al Seadi et al., 2013; Slopiecka et al., 2022). Users of biofertiliser products need confidence that the producer has understood their feedstock to produce a good product.

A summary of typical chemical characteristics of source separated food waste across the world is presented below, along with chemical analysis from different food groups (Banks et al., 2018; Slopiecka et al., 2022). However, international comparison is difficult due to differing sample sizes, methods of analysis, and variables associated with its collection, although it does give a general indication of parameter ranges (Banks et al., 2018). Table 1 lists some general chemical parameters from the UK study. Parameters were selected on the basis that they may influence the processing or final composition of digestate.

Table 1: Biochemical characteristics of source- separated food waste in the UK. Adapted from Banks, et al., 2018.

Parameter (g/kgf^{-1}TS, unless otherwise stated)	Value
pH	5.02
Total solids (TS) (% fresh matter)	25.89
Volatile solids (VS) (% fresh matter)	24.00
Total organic carbon (% TS)	48.76
Total Kjeldahl nitrogen	29.1
Total phosphorus	2.82

Parameter (g/kfg⁻¹TS, unless otherwise stated)	Value
Total potassium	8.59
NPK ratio	10:1:3
Cobalt	0.15
Iron	111
Manganese	86.5
Selenium	0.42
Chromium	4.21
Copper	5.69
Lead	<0.6
Zinc	22.4

Results of the analysis of individual food groups (trace minerals not included) obtained from expired food are useful when comparing different potential feedstocks for the purposes of producing biogas. The NPK ratios and other parameters of the different food groups are listed in Table 2.

Table 2: Chemical characterisation of expired food waste, adapted from Slopiecka, et al. (2022).

Food waste group	pH	TOC (%)	Total solids (%wet biomass)	Volatile solids (% wet biomass)	NPK ratio
Dairy	6.29	29.72	38.54	36.65	2:1.5:1
Fats	3.55	65.64	60.75	569.29	5:1.5:1
Fruits and vegetables	5.69	19.57	13.87	12.17	1:1:5
Meat	6.20	25.18	46.99	41.6	7:1:1
Fish	6.49	17.72	46.12	39.25	3:1:1

Banks et al., (2011) listed the key parameters and their influences on AD, noting that for the optimum production of biogas (a high value product) parameter ranges must be strictly controlled and therefore they determine the final composition of digestate, for example:

- The fraction of volatile solids to total solids helps to determine the speed of the digestion process. A higher VS/TS ratio means more feedstock can be consumed by bacteria, however this results in less digestate output;
- Nutrient ratios, while also determining the makeup of digestate, can also affect growth of bacteria during digestion, e.g. high nitrogen combined with low carbon can result in the formation of ammonia, which is toxic to methanogenic bacteria (key bacteria used in AD);
- pH of 7-7.5 is optimum for a healthy population of bacteria.

High quality digestate comes from good control on feedstock selection and control of the production process, which also reduces the likelihood of contamination and negative environmental effects. This is achievable through accreditation of producers. Click or tap here to enter text.This is discussed in further detail in **Section 4**.

2.2 Properties of Digestate

Table 3 summarises the components of digestate. Parameters were selected based on their relevance to fertilisers. These are not the only component analysis results available however the extent of the analysis and units used in other studies make it difficult to undergo a direct comparison.

Table 3: Components of typical digestate.

Form of Digestate	Total solids %	$TAN_{(total\ ammoniacal\ nitrogen)}$ (g/kg of total solids	P_{total} (g/kg of total solids	K_{total} (g/kg of total solids	NPK Ratio	Study reference
Solid (from food waste)	14.7	23.6	18.0	10.5	2:2:1	Banks, et al., (2018)
Liquid (from food waste)	5.84	65.1	46.1	11.5	5:4:1	Banks, et al., (2018)
From food waste	N/A	52-108	6-16	26-81	N/A	Lu, et al., (2021)
From food waste (wet basis)	7.52	81.7	0.76	1.05	107:1:1	(Sánchez-Rodríguez et al., 2018)
From food waste	1.21	1.15	0.46	0.38	3:1:1	(Jamison et al., 2021)

There are large ranges in the data presented highlighting that differences in the AD process and in the recipe of the feedstock can affect the composition and quality of the final product. The data provided in Table 3 is for digestate prepared for experiments, and not as a certified biofertiliser. Nutrient ratios of certified biofertilisers are expected to have much less variability.

Organic matter is an important component of biofertiliser as it provides structure to the soil, increasing water retention and enhancing nutrient uptake in plants (Rivier et al., 2022). Digestate has a moderate amount of organic matter; less than in compost, for example, but well above that of synthetic fertilisers, which have a negligible amount of organic matter. Well-rotted compost may have a carbon to nitrogen (C/N) ratio of 25-30. The C/N ratio in some food waste sourced digestate may be between 2 and 7 (Lu & Xu, 2021; Opatokun et al., 2016), driven by typically large amounts of ammonium that can be found in digestate.

The organic matter content can be estimated by the proportion of volatile solids (VS). A higher percentage of VS indicates a larger amount of organic matter present and so are advantageous for biogas production. Food waste derived digestate may have a VS range of 21 – 73.6% (Lu & Xu, 2021; Opatokun et al., 2016)

The mix of nutrients and organic matter demonstrates how digestate can give crops the “best of both worlds” when certified by acting as a soil conditioner, and a fertiliser. More information on the direct benefits of digestate is given in **Section 4**.

The above information can help users understand the components of digestate and choose the best biofertiliser product for their soil and crop needs.

2.3 Biogas and Digestate: Key Takeaways

- The production of biogas requires feedstock, which can be sourced from food, crops, or other types of industrial organic waste. Digestate is the secondary product from biogas.
- As New Zealand shifts to a zero carbon, climate sensitive country, biogas is likely to become more relevant. BANZ have established an accreditation schemes to ensure that when products come to market, users can have confidence in their suitability, distinguishing them from raw digestate product which can carry environmental, economic, and usability risk.

- Food waste is suitable to produce digestate as it contains organic material, and range of nutrients and trace elements. Use of food waste may divert it from landfill, although public focus is on the reduction of food waste, not as an energy source.
- A high proportion of volatile solids is beneficial for fertiliser and for biogas production.

3 Agricultural Uses of Digestate

Soils world-wide are becoming diminished in their ability to retain water and nutrients, which affects crop production (Jie et al., 2002). With global increases in food demand, maintaining or increasing crop yields is essential. In addition to this, urban sprawl is rapidly claiming productive soils requiring more intensive methods to increase output from a smaller land area (Gardi et al., 2021). These methods often require the increase in the application of conventional, nitrogen-based fertilisers, and while they do help with crop yields, over-use or poor management can cause negative environmental effects. These include excess nitrogen leaching into freshwater environments, a reduction in soil microbial communities, and the contamination of groundwater.

3.1 International Success

In the United Kingdom, the Waste and Resources Action Programme (WRAP) commissioned 22 field experiments utilising biofertiliser across three growing seasons that demonstrated increased yields (winter growing wheat) with no adverse effects on crop quality or the environment. The experiments showed an increase nitrogen use efficiency when applied in spring (almost 60% more than in autumn) and resulted in a 0.55t/ha (85% dry matter) increase in yield over crops that were fertilised with conventional products. Heavy metals and other contaminants were also analysed within the soil and were found to be well below regulatory limits (WRAP, 2016). The data provided by this study has been built into fertiliser planning tools and guidance that is easily accessible for farmers, helping them assimilate biofertiliser into their farm management.

In Canada, incorporating biogas production in tandem with traditional farming is becoming more commonplace. Farmers can use on site feedstock and top up with food waste to produce biogas, which can then be injected into mains gas. The digestate produced can be reapplied onto the farm as fertiliser or sold to other farms. Not only does this have significant circular economic and environmental benefits, but also allows farmers to diversify incomes and provide wider benefits to local economies (Farming Biogas Canada). Additionally, Farming Biogas Canada supply practical guides on applying digestate to different crops in different seasons, or with different sources of digestate (e.g. food waste versus manure slurry).

The production of biogas and the use of digestate in Germany is well established and quite common with a set of developed guidance and schemes. Nearly 10,000 biogas plants were in operation as of 2022, which were largely driven by energy crops but now is shifting towards organic waste products as feedstock due to regulation change. 97% percent of digestate produced by biogas plans are used in agriculture, with the remainder for landscaping and other purposes. Certified biofertiliser is available from 171 digesters as at 2017 (World Biogas Association, 2019).

3.2 Scientific Review

The below discussion contains information primarily sourced from peer reviewed, scientific research, and features digestate produced under experimental conditions.

3.2.1 Digestate as a soil improver

The heavy use of fertilisers is essentially "putting a bandage" over the problem of the degrading quality of productive soils (Adekiya et al., 2024a). Alternative methods to regular fertiliser use to help improve soil properties include sowing cover crops over winter, particularly those that are nitrogen fixing (legumes such as peas, fava beans or vetch), or working crop residues back into the soil following harvest to break down naturally and thus increase the soil organic matter fraction.

Ren et al., (2020) and Adekiya et al., (2024a) found that biofertiliser provides a range of minerals, enhances soil structure through the provision of organic carbon, and provides an increase in microbial bioactivity. Furthermore, where digestate is certified and the inputs are known and controlled, the composition and quality of the output digestate becomes more predictable, and farmers can better plan their fertilising regime.

The key benefits of digestate as a soil conditioner are:

- Digestate has been shown to improve the organic carbon (OC) content and increase key mineral concentrations of soil especially in combination with synthetic fertilisers (Adekiya et al., 2024b; Ren et al., 2020);
- In Ren, et al., (2020), digestate significantly increased the relative abundance of two bacteria taxa, whilst urea decreased them. It also increased hyphal fungal length, increased accessibility to ammonium, readily converting it to nitrate, which in turn allowed better uptake by the plant. Digestate did not increase microbial richness or community diversity, however urea by comparison decreased microbial richness and community diversity. This research highlighted the need for soil improvers or fertilisers that help retain existing soil properties, while in some respects improving them. Ren, et.al. (2020) concluded that conventional fertilisers are not typically fulfilling this need;
- Rivier et al., 2022 suggest that research into the effects of digestate on soil structure is very limited. There may be slight changes in soil texture and promotion of water stable large aggregates in a loamy soil with the application of digestate, related to organic carbon and minerals within the soil. Digestate may also improve water retention in soils with poor structure (e.g. sandy soils). This effect proved to be less prevalent in soils that are loamy (Rivier et al., 2022).

Key considerations:

- The effects of digestate as a soil improver are more measurable in less fertile, poorly structured soils. Soils in many parts of New Zealand, especially those in the Canterbury and Otago Regions may benefit from the application of digestate.

3.2.2 Digestate as a Fertiliser: Crop yields and effects

Rural production is heavily reliant on the use of nitrogen based synthetic fertilisers, which helps to produce crops with consistent yields. In this case, synthetic fertilisers refer to urea, super phosphate and other similar products. While there is certainly a place for these types of fertilisers, alternatives should also be considered if they enhance crop yields, potentially improve soil structure, reduce fertiliser costs, and help farmers stay under nitrogen limits.

Digestate as a fertiliser undoubtedly improved crop yields in both paddock and greenhouse settings (Adekiya et al., 2024b; Cheong et al., 2020; German Biogas Association, 2018; Sánchez-Rodríguez et al., 2018). Key outcomes from research includes:

- Digestate improved crop yields both on its own (in comparison to no application of any fertiliser) and in combination with synthetic fertilisers (Sánchez-Rodríguez et al., 2018);
- Rate of application influenced outcomes: high rates may favour leafier growth while low rates support soil properties and overall grain yields (Cheong et al., 2020);
- Digestate differs to conventional fertilisers in that it contains both ammonium and organic nitrogen, the former being rapidly available to plants, and the latter undergoing slower, long-term release (German Biogas Association, 2018);

- A combination of synthetic fertilisers and digestate may increase the efficiency of nitrogen use than synthetic fertiliser alone in a greenhouse facility. Digestate may provide up to half the nitrogen required for kai choy (a brassica) (Jamison et al., 2021);
- Root growth (length and biomass) may be improved during rapid growth phases after the application of biofertiliser, however there is no consensus in research to confirm definitive benefits in a greenhouse facility (Jamison et al., 2021).

Key considerations:

- Feedstock composition may affect crop yields due to the potential for high concentrations of salts when digestate is applied at high concentrations. This may be able to be controlled with the use of biochar (which can also be derived from digestate) to help reduce the effects of varying salt concentration and pH (Cheong et al., 2020; Jamison et al., 2021; Lee et al., 2021; Liu et al., 2020).
- The high amount of ammonia present in typical liquid digestate can be easily lost in volatilisation upon application (30-50% of total nitrogen)(Nicholson et al., 2017). Prevention of this is typically controlled by acidification (i.e. lowering the pH to about 6) or method of application (e.g. dribble bar or direct injection) which reduces volatilisation rates.
- Experimental research suggests that nitrification may be required if digestate already has high levels of ammonium. Nitrification is facilitated by microorganisms in aerobic conditions to oxidise ammonium to nitrite and ultimately nitrate (Ries et al., 2023; Sánchez-Rodríguez et al., 2018). This requires further processing beyond the production of biogas, as that process relies on methanogenic bacteria present during AD. High ammonia levels can also be mitigated by adjusting dilution and application rates.

3.3 Agricultural Uses of Digestate: Key Takeaways

- Biogas plants and the production of digestate is well established throughout the UK and Germany and is becoming more common in Canada. The use of digestate as a fertiliser, and the incorporation of biogas plants onto traditional farms has numerous circular benefits with supporting field trial results.
- Digestate as a soil improver may perform best in soils which are poorly structured and infertile, therefore have the most to gain from digestate benefits.
- Digestate may help to improve microbial activity in soil.
- The organic content digestate provides to soil may improve nutrient availability to plants.
- Good crop yields can be gained from using digestate in tandem with synthetic fertilisers.
- Additional soil amendments such as biochar may be added to adsorb any excess salts.
- Lower rates of application may benefit overall plant growth and health.
- Experimental research suggests that nitrification and pH amendment is recommended to reduce levels of ammonia in all forms of digestate. Application by dribble bar, or direct injection is also effective at reducing volatilisation of ammonia.

4 Confidence in Digestate as a Biofertiliser

4.1 Certification and accreditation schemes in New Zealand

In current New Zealand law, biofertiliser is defined as an agricultural compound under the Agricultural Compounds and Veterinary Medicines (Exemptions and Prohibited Substances) Regulations 2011 (ACVM). Fertilisers, plant biostimulants, and soil conditioners are all exempt from registration under the ACVM Act 1997 but must carry nutrient information. Additionally, products marketed as compost, mulches, and soil conditioners (but not those marketed as fertilisers) must comply with NZS 4554:2005 which sets out contaminant limits and testing procedures (New Zealand Standards, 2005).

By nature, food waste feedstock is variable and the opportunity to control its composition is limited to source separation. The Bioenergy Association of New Zealand (BANZ) has established such a scheme, which aims to not only standardise the product available to farmers, but also to enable a different pathway for digestate (Bioenergy Association, 2023). In addition to this Water New Zealand released a draft guide on the Beneficial Use of Organic Materials on Productive Land, which aimed to help create a consistent approach to the management of these materials in New Zealand. This supports documentation released by BANZ.

The risk of variation in composition is low for conventional and synthetic fertilisers as mass production requires controlled processes, and thus the end-product is generally reliable. Fertilisers from well-known companies such as Ballance and Ravensdown are listed under the voluntary certification scheme Fertmark, operated by the Fertiliser Quality Council. Fertmark independently verifies products to make sure labels match the contents, ensuring that users can have confidence in the product.

The advantages of such a scheme include regulation of the input of nutrients into farm systems, and providing certainty to processors and regional authorities that the fertilisers are being used responsibly. Only one biofertiliser (derived from fish waste) is currently listed on Fertmark's approved product list

Overseas, certification schemes and legislation controlling the digestate products are generally well developed (Bioenergy Association, 2023; British Standards Institution, 2014; End of Waste Code for Digestate, 2022; Environment Agency United Kingdom, 2014). Typical aims of these schemes and documents are like those described for Fertmark. Please see **Section 3.5** for further details on international schemes.

Minimum criteria for digestate to be used as fertiliser are available in many countries, and the New Zealand Bioenergy Association has produced guidelines from various sources that fit within the New Zealand regulatory environment (Bioenergy Association, 2023). The Guidelines for Beneficial Use of Organic Materials on Productive Land (2017) also contains suggested limits.

Key considerations included in current Guidelines for the Production of Digestate Fertiliser for Application to Land (aside from contaminants which are covered in **Section 3.3)** are included in Table 4:

Table 4: Draft key parameter standards for digestate (Bioenergy Association, 2023)

Parameter	Standard
Nitrogen	Aggregate of all parameters or equal to 3% dry weight
Phosphorus	
Potassium	
Magnesium	
Calcium	
Sulphur	
Volatile fatty acids	0.774g COD/g VS

Parameter	Standard
Total stones	Dependant on total N (kg/t)
E. coli	Less than 100 MPN/g
Campylobacter	Less than 1/25g
Salmonella	Less than 2 NPM/g

4.2 Related Laws

4.2.1 National Laws

New Zealand only limits nitrogen application for synthetic fertilisers for the purposes of reducing nitrogen runoff into waterways (Ministry for the Environment, 2021). The guidance determines that any fertiliser containing more than 5% of its weight in nitrogen is classified as a synthetic fertiliser. Application limits are listed below:

- For grazed pastoral land, no more than 190kg/hectare of synthetic nitrogen per year;
- For annual forage crops, the above cap may be exceeded if the average for all pastoral land use is kept within the cap;
- For other pastoral land use (intermittently used for grazing but is primarily used for other purposes) the above cap may be exceeded if the average for all pastoral land use is kept within the cap.

There are no restrictions for dairy farms, however dairy farms must submit annual nitrogen reports.

While digestate products may not reach the 5% weight threshold, it's recommended that farmers build the planned use of digestate into their farm nutrient budgets and include it within the 190kg/hectare cap to avoid adverse environmental effects. This is especially important as digestate can contain high concentrations of ammonia.

4.2.2 Regional Rules

Farmers should also refer to Regional Plans, where allowed nitrogen applications may be different to those stipulated by the Ministry for the Environment.

Food waste derived digestate, when marketed as a fertiliser or soil conditioner, is usually defined as a fertiliser under most Regional plans, and therefore rules relating to fertilisers will apply. However, if digestate is derived from human or animal waste, it more likely is defined as a biosolid, and may be subject to different rules. The way digestate is processed may also affect these definitions.

An accredited producer of digestate will be able to inform users of which definition, and which Regional rules, apply to its use. Users are also encouraged to check their Regional plan for confirmation especially if they intend to apply it at high rates, and/or are near significant waterbodies (e.g. lakes and rivers).

4.3 Contaminants in Uncontrolled Digestate

Contaminants are now being detected across the world in many products, from our food to our water and soil. Organic soil amendments derived from food waste may be susceptible to contaminants as it is heavily influenced by humans. Contaminants may range from heavy metals, emerging contaminants, to microplastics, although actual prevalence has not been widely explored in New Zealand. Some of these contaminants have no environmental health criteria for comparability so good evidence is needed to support the selection of contaminant limits in biofertiliser, being cognizant that repeat application may provide significant accumulation effects in the soil.

Contaminants that have been detected in food waste digestate are listed below:

- Emerging contaminants (Kupper et al., 2006)
  - Polychlorinated biphenyls (PCBs)
  - Per and poly-fluoroalkyl substances (PFAS)
- Organic compounds (Kupper et al., 2006)
  - Polycyclic aromatic hydrocarbons
- Heavy metals (Golovko et al., 2022)
  - Cadmium, chromium, copper, lead, mercury, nickel, zinc.
- Microbiological and parasitological in feedstock (Bonetta et al., 2014; Parra-Orobio et al., 2021)
  - Faecal coliforms
  - *Giardia spp.*
- Physical contaminants, such as dirt, stones and microplastics (Bioenergy Association, 2023)
  - Microplastics have been found within food waste in Europe and are likely present in New Zealand (Porterfield et al., 2023)

Complete removal of contaminants during the AD process can be difficult, or in some cases impossible however with good management the actual risk of contaminants causing harm can be reduced. (US Environmental Protection Agency, 2021). In New Zealand, control starts at the household - recent changes to food and garden organic (FOGO) waste collection means that packaging, even if marked as “compostable” are not allowed within scrap bins, due to the risk of introduction of chemical and physical contaminants (such as PFAS and microplastics) into the environment (Ministry for the Environment, 2023a).

Biological contaminants can be reduced to very low concentrations or to zero detection via pasteurisation, which is a thermal treatment at about 70°C (Zhang et al., 2020). However, for the remainder of chemical contaminants, management is in the form of establishing evidence-based standards for contaminants to prevent adverse environmental or human health effects, where digestate is used to grow crops intended for consumption. BANZ has produced a Technical Note on feedstock categories, which gives further information on pasteurisation, land use considerations, and labelling (Digestate Biofertiliser Producer Accreditation Scheme Technical Note 12, 2024).

4.4 Contaminant Limits and Risk Mitigation

BANZ have developed their biofertiliser guidelines to manage contaminant risks via process that targets all aspects of production (Bioenergy Association, 2023):

- Controlling the type of feedstock suitable for digestion, such as only allowing abattoir waste that has been marked as fit for human consumption but is otherwise not suitable for sale.
- Apply further conditions to suitable feedstock, which include clarifications for feedstock which may fall between accepted types e.g. lawn clippings may have low risk of slowly degrading herbicides but digestate formed from this could still be suitable for high energy crops.
- Application of contaminant limits (see Table 6).
- Requirement for producers to implement a Facility Risk Management Programme to demonstrate reliability and consistency of the product, including sampling the product to ensure that limits are not exceeded.

BANZ has developed contaminant limits for its digestate biofertiliser scheme, based primarily on British Standards and the NZ 4454:2005 (Bioenergy Association, 2023). Standards for the biofertilizer scheme were selected based on their relative risk in digestate. Maximum limits are given in Table 5.

Table 5: Contaminant limits, sourced from DBPA 05, v1 (2023) Bioenergy Association unless otherwise stated.

Contaminant	Limit (mg/kg unless otherwise stated)
Arsenic	30

Contaminant	Limit (mg/kg unless otherwise stated)
Boron	200 (NZS 4454:2005)
Cadmium	10
Chromium	1500
Copper	1250mg/kg
Lead	300mg/kg
Mercury	7.5mg/kg
Nickel	1500mg/kg
Selenium	5 (AS4544-2012)
Zinc	135mg/kg
Total contaminants >2mm	Dependant on nitrogen content in kg/t
Total stones >5mm	Dependant on nitrogen content in kg/t
DDT/DDD/DDE*	0.5 (NZS 4454:2005)
Aldrin*	0.02 (NZS 4454:2005)
Dieldrin*	0.02 (NZS 4454:2005)
Chlordane*	0.05 (NZS 4454:2005)
Heptachlor	0.02 (NZS 4454:2005)
Hexachlorobenzene (HCB)**	0.02 (NZS 4454:2005)
Lindane*	0.02 (NZS 4454:2005)
Benzene hexachloride	0.02 (NZS 4454:2005)
PCBs*	0.5 (NZS 4454:2005)
E.coli	<100 MPN/g
Campylobacter	<1 per 25g
Salmonella	<2 MPN/g
Plant material	Must not contain any parts of a plant which may germinate into a new plant.

* Prohibited from use as agricultural compounds or as agricultural compounds in New Zealand (ACVM Regulations, 2011)

** Prohibited from use as agricultural compounds or as agricultural compounds except as an impurity in other active ingredients in New Zealand (ACVM Regulations, 2011)

Contaminants listed in NZ 4544:2005, but not included in BANZ limits have either been banned in New Zealand and are now legacy chemicals or are associated only with agricultural pest control and so are highly unlikely to be found in food waste. However, if research shows that any of these contaminants become relevant then they may be included with limits in future iterations of the BANZ limits.

4.4.1 Emerging Contaminants & Exotic Diseases

The limits provided in Table 5 do not include emerging contaminants, microplastics, or guidance around exotic disease detection in biofertilizer. Research into determining how these types of contaminants should be controlled is still developing, and staying abreast of this research is the most pragmatic way of minimising harm in the environment. It also serves to identify areas that may need further work or controls, rather than be seen as barriers to the growth of digestate use in New Zealand.

Table 6 describes examples of risks from emerging contaminants and diseases where measurable limits do not yet exist.

Table 6: Emerging contaminant risks and identified controls.

Risk	Control & Management	Residual Risk
Introduction of contaminants which do not yet have limits and later prove to harm, or have not been previously detected, or increase concentrations of contaminants above baselines.	• Stay abreast of research and development of limits in New Zealand and internationally. Stay engaged with stakeholders and communicate new research as it eventuates through Technical Note releases. • Clear, straightforward labelling that tells users there is some risk of introducing contaminants. • Identify which feedstocks are likely to contain emerging contaminants and submit feedstock samples for testing. • Match feedstock to suitable uses i.e. feedstock with a high risk of contaminants should not be applied as biofertiliser to dairy farms.	Implementation of procedures to manage risk is only as good as those who are responsible for following procedures. Failure to adhere could cause contaminated biofertilizer to be sold at concentrations high enough to have toxic effect.
Introduction of contaminants which are highly mobile (such as PFAS) into sensitive environments.	…as above, plus • Ensure end users clearly understand the restrictions and risks around applying biofertilizer near sensitive environments. • Wide distribution of well marketed, easily understandable information to users.	…as above, plus User failure to understand the environmental consequences and ignorance of laws surrounding the application of fertilisers in sensitive environments.
Introduction of biological diseases not yet found in New Zealand.	• Strong control of allowable feedstocks • Careful management of AD to kill pathogens. • Use of locally derived feedstock only • Consultation and open communication with Ministry for Primary Industries (MPI). • Seeking international case studies. • Implementation of tracing method of biofertilizer products once sold.	Accidental introduction of diseases that survive the AD process.

The BANZ accreditation scheme draws heavily from best practice and successful schemes in the United Kingdom, where the forefront of policy and science-based contaminant research exists. Papers released on investigations into microplastics in digestate, for example, are clear in the need for a holistic approach to managing risk, requiring input from producers of digestate and feedstock (which can include household education), policy makers, and academic researchers (Longhurst, et al., 2019, Porterfield, et al., 2022; WRAP, 2022).

While there will always be residual risk related to contaminants, implementation and follow through of controls to manage contaminants in conjunction with staying abreast of research and consultation relevant organisational bodies (e.g. MPI, Fertmark) the actual severity and likelihood of negative effects occurring are likely to be manageable. The Guidelines for Beneficial Use of Organic Materials on Productive Land (Draft) (2017) also provides additional information for risk management.

4.5 Problems with uncontrolled digestate

Farmers may choose to use uncertified digestate to reduce costs. However, this could have legal, social, and environmental ramifications. Some examples of uncontrolled digestate features and consequences are described below:

Table 7: Consequences of uncertified digestate use.

Feature of uncontrolled digestate	Consequence	Compared to accredited biofertiliser
False, partial or no product labelling.	A purchaser may be misled and inadvertently apply too much of the product or introduce contaminants to the soil. Consequently, they may exceed nitrogen limits.	Labelling is transparent, backed by testing and accreditation giving users confidence in the product. Users can rely on labelling to comply with nitrogen limits.
No storage, or application guidelines/rates	Product may be stored incorrectly leading to volatilisation of ammonia which can also cause odour problems. As above, the product may be applied incorrectly resulting in under or over fertilisation which may pollute waterways and exceed nitrogen limits.	Inclusion of storage and application guidance gives the best outcomes for nutrient balances and reduces the risk in environmental harm.
No quality assurance or control information available for the production process	Product may not have been suitably digested and/or pasteurized to provide a safe and usable digestate. Users may apply digestate containing unsafe levels of pathogens/other contaminants which have risks to human health and the environment.	Users have confidence that their product has been suitably pasteurised and have a good understanding of the level of risk from measurable contaminants.
No testing of the product, or testing not completed in accordance with NZS ISO/IEC 17025 and/or recognised by IANZ (International Accreditation New Zealand)	Contents of the product cannot be guaranteed, user is exposed to animal, human, and environmental health effects.	Contaminants are controlled precisely to a recognisable standard.
No information on type of feedstock used.	The user may apply digestate derived from unpalatable feedstock (e.g. wastewater treatment waste) to food crops. This could influence how the crop is marketed to buyers.	Users know which type of agriculture the product is best suited for e.g. energy crops grown to produce biofertiliser may have a higher risk of containing pesticide residue and so are unlikely to be suitable for dairy farms.
No information on its definition or activity status under Regional Rules.	User may undertake an unconsented activity.	Users can comply with nutrient application rate limits and setbacks within their region.

4.6

4.6 Confidence in Digestate as a Fertiliser: Key Takeaways

- The Bioenergy Association of New Zealand has produced accreditation schemes based on best practice, successful schemes overseas and published research. They aim to work with Fertmark to help bring a reliable product to market.
- Understanding the prevalence and risk of emerging contaminants, microplastics, and exotic diseases in digestate is in its early stages, and there are no accepted limits for such contaminants. Staying abreast of international research and accreditation scheme updates, plus maintaining open communication with relevant parties in New Zealand (e.g. MPI) are some of the ways risk can be managed.
- Using uncontrolled digestate may expose the user to human, animal, and environmental risk. It may also skew farm nutrient budgets. Use of producer accredited biofertiliser greatly reduces these risks or eliminates them.
- Biofertiliser should be accounted for in farm nutrient plans.
- Regional Plans may have their own definitions of digestate. Producers should supply users with this information as different definitions may have a different activity status.

5 Application to Land

Methods of application of biofertiliser may constitute one of the greatest constraints to its use in New Zealand. Because it typically has a higher pH and NH_4 content than mineral fertilisers, the risk of loss in the form of ammonia is high (Wilken et al., 2018). While it is a large barrier to overcome, there is much that can be learned from overseas practices, particularly in the United Kingdom and Germany where biofertiliser application to land is a common practice.

Infrastructure and equipment required to store and apply biofertiliser is somewhat uncommon in New Zealand (particularly for storage), however these barriers can be broken down as the BANZ scheme becomes widely adopted and production/usage ramps up.

5.1 Best Practice

5.1.1 Storage and Handling

Biofertiliser may rapidly volatise ammonia if left uncovered. It may be either stored at the production plant, or where it is planned to be applied, and in both cases must be completely enclosed above ground and be gas tight, such as in storage tanks with a soft gas membrane. This is essential to prevent dilution by rainwater and avoid serious environmental effects, such as contamination to surface water or groundwater (Seadi et al., 2010).

Storage in a lagoon is also possible for liquid biofertiliser, but it must have a “crusting” surface, for example a layer of chopped straw or clay granules and must be stirred just before use. Examples of storage types are shown below in Figure 3. While dry biofertiliser may not have as higher risk of volatilisation, it should still be kept dry to guarantee its performance. With no requirements for gas control, dry biofertiliser may be cheaper to store and transport.

Figure 3: Left - Biofertiliser storage tank covered with gas tight membrane (soft cover). Right - open storage tank with straw on the surface (Seadi et al., 2010).

Handling requirements are similar to what is required for spreading dairy effluent or conventional solid fertilisers which are very common practices in New Zealand. Care must be taken to minimise the biofertiliser exposure to air while it is in liquid form, to reduce volatilisation. Biofertiliser typically contains low or negligible amounts of microbiological contaminants compared to dairy waste, although care should still be taken to not touch biofertiliser with bare skin.

5.1.2 Dust and Odour

Any odour from liquid biofertiliser would likely be due to the volatilisation of ammonia. This can be avoided by storing biofertiliser in a way that prevents the release of gases. Biofertiliser should also be applied as soon as possible after drawing it from a tank/lagoon to minimise odour release.

Odour may also be controlled through the correct selection of spreading equipment i.e. shallow injection or dribble bars will result in less volatilisation than splash plate spreading.

Dust is likely only an issue where dry biofertiliser is mechanically broken down in high winds. This can be avoided by working biofertiliser directly into soil and avoiding windy days - which is also required for the application of conventional fertilisers.

5.1.3 Climatic and Land Conditions

Much of the usual climatic conditions that determine optimal timing for the application of conventional fertilisers are also true for the application of biofertiliser. However, care must be taken to reduce the excessive leaching of ammonia and salts into the environment. Some biofertiliser undergoes amendment to pH and nitrification, or the addition of biochar to reduce the amount of ammonia or salt that can be leached, reducing risk to environmental harm and increases the chances of a good crop yield. Recommendations for the application of biofertiliser are listed below:

- Liquid biofertiliser should not be applied during rain or when significant rainfall is forecast, or on windy days;
- Dry biofertiliser may be applied when soil is damp, it is raining, or rain is forecast to speed up its breakdown in soil;
- No biofertiliser should be applied when the soil is waterlogged;
- No biofertiliser should be applied within 50m of any spring, well, reservoir or borehole that supplies water for animal or human consumption (WRAP UK, 2016);
- No biofertiliser should be used on steep slopes or within 10m of surface water features (WRAP UK, 2016);
- No biofertiliser should be applied where ponding could occur (e.g. from winter pugging). Soil may need to be worked to ensure an even surface for application.

When biofertiliser is used as a soil improver, testing should be undertaken on the soil to determine the level of improvement biofertiliser may bring. For instance, a well-structured, fertile volcanic soil type may not benefit much from the use of biofertiliser. Conversely, a poorly structured and less fertile soil may benefit hugely from biofertiliser, and management requirements could be well worth these benefits.

Soil might include:

- Determination of soil structure if not already known;
- Organic matter content;
- Microbial activity;
- Cation exchange capacity.

5.2 Practical Application

In Europe, where the application of biofertiliser is common, methods of application are very well established. As mentioned earlier application methods are the same used for spreading dairy effluent, except for the use of splash plates (surface broadcasting method), which are banned in several countries due to significant pollution risks and high rate of ammonia loss and are not recommended by BANZ (Nicholson et al., 2017; Seadi et al., 2010). The gold standard of biofertiliser application is by dribble bars or direct injection. Examples of this type of equipment are shown in Figure 4.

Figure 4: Left – dribble bar application of biofertiliser. Right - direct injection of biofertiliser (Seadi et al., 2010) .

Solid biofertiliser may be applied with the same equipment used to apply dried manure (Figure 5).

Figure 5: Typical manure spreader, also suitable for spreading solid biofertiliser (Source: Kuhn.com).

5.3 Other factors

Additional factors to consider when applying biofertiliser to land are:

- A withholding period for grazing (21 days), based on the risk assessment for biofertiliser application to land, prepared by Ecogas in response to MPI's review of the risk framework on the spontaneous outbreak of bovine spongiform encephalopathy and the subsequent possibility of ruminant protein application to grazing land being banned. For pig grazing, the withholding period is 60 days. Please refer to DBCS Technical Note 12 (Bioenergy Association of New Zealand, 2023) for additional information.
- Costs. Liquid biofertiliser will be more expensive to store and apply, as specialised storage is required to prevent volatilisation and specific equipment is needed to apply it. Dry biofertiliser may be more expensive to source due to the producer needing to dry the biofertiliser before sale, although storage and application will likely be cheaper than that of liquid biofertiliser (WRAP UK, 2016).
- Application depth. In the Waikato Region, the application depth of dairy effluent may not be more than 25mm. Without guidance for application of liquid biofertiliser this depth likely to be suitable.

5.4 Environmental Effects

The application of biofertiliser to land may have several environmental effects, both negative and positive. Negative effects are likely to be more related to the localised application of biofertiliser to land and can be mitigated easily. Positive effects are broad and related to good climate outcomes.

Positive environmental effects relating to the use of biofertiliser include the following:

- Biofertiliser is a by-product from the production of biogas. Using it as fertiliser diverts it away from landfill;
- Use of food waste as feedstock diverts the food waste from landfill, turning it into a high value product;
- Completion of the nitrogen cycle – organic material is returned to the land in a form usable by plants instead of being lost to air, water, or buried (Banks et al., 2018).
- Reduction in reliance on synthetic fertilisers which could reduce nitrogen runoff into the natural environment.
- Potential for long term improvements in soil health which can support future crops and reduce the need for high intensity agriculture.
- Closing the loop of circular economic and environmental principals.

Table 8: Potential negative effects from biofertiliser application.

Potential Negative Effect	How can the effect be mitigated?
Increase in contaminants in soil that can't be removed by the AD process	Use biofertiliser that is sourced from an accredited supplier.
Increase in nitrogen laden runoff	Store biofertiliser appropriately. Do not spread liquid biofertiliser during or before forecast rain, and do not spread near waterways. Don't use splash plates for spreading.
Release of ammonia to air (harm to people or animals, eutrophication of water bodies) (Nicholson et al., 2017)	Store and spread biofertiliser according to crop needs and spread as soon as possible after removal from storage. Click or tap here to enter text.
Nitrate contamination of groundwater	Minimise depth of application and do not apply during or before forecast rain, and do not spread near waterways.
Release of nitrous oxide (greenhouse gas)	Reduce release by applying biofertiliser to actively growing crops.

Negative effects can be seen as opportunities to explore ways to improve how biofertiliser might be used in New Zealand.

5.5 Click or tap here to enter text.Application to Land: Key Takeaways

- Liquid and slurry biofertiliser volatilise ammonia gas rapidly upon contact with air. Proper storage and handling is required to reduce this, usually in the form of a tank with a soft gas membrane. All forms of biofertiliser must always be contained and covered to prevent leaching.
- Odour is related to the volatilisation of ammonia. Prevention of volatilisation, and using suitable application methods, will help minimise odours. Dry biofertiliser may produce dust as it is worked into the soil if it is windy at the time of application.
- The climatic and land conditions required for the application of biofertiliser are similar to those required for other fertilisers.

- Spreading of liquid biofertiliser by splash plates is not recommended. Dribble bars or surface injection are preferred, and solid biofertiliser may be applied by conventional manure spreaders.
- Negative environmental effects are localised and can be minimised by good practice.
- Positive environmental effects fit with circular economy principles.

6 Social and Cultural Considerations

In New Zealand, the use of digestate as a fertiliser or soil improver is still untested and largely unknown. As such there are several challenges that need consideration.

- Using biofertiliser will challenge conventional farming practices. Synthetic fertilisers work well for most farmers – clear communication in marketing material will be required to demonstrate that biofertiliser is a great alternative to or a supplement for synthetic fertilisers.
- The use of biofertiliser originating from food waste may be a challenging concept for users producing food crops, due to the use of the word “waste”. Changing the language around feedstocks will be essential to market the biofertiliser as a safe product. Clarity on the production process – i.e. pasteurisation to kill pathogens will also need to support the language used.
- Pasteurisation and AD does not remove heavy metals, organic contaminants, or other emerging/microplastic contaminants. Producers will be required to meet strict quality control and assurance processes to reduce risk of contamination in the environment. Emerging contaminants and microplastics are new considerations for biofertiliser and extensive research and consultation is needed before safe, evidence-based standards can be adopted.
- Using biofertiliser to improve previously poorly structured and infertile soils to enable good crop growth may provide economic and social uplift for a famer or a whole region. However, with biofertiliser untested in New Zealand, the scale of this benefit is hard to define.
- There is no information on how Māori might receive the use of food waste as a fertiliser to help produce crops. Consultation and study are required to further understand Māori perspectives.

7 Conclusions

There is huge potential to produce biofertiliser from digestate in New Zealand, with many international examples to learn from. An accreditation scheme has been developed, and there is a wealth of scientific research which supports the use of biofertiliser as both a fertiliser and a soil improver.

However, this comes with some challenges, such as reframing traditional farming practices, marketing considerations, cultural unknowns, and the need to develop infrastructure which is uncommon in New Zealand. The BANZ accreditation scheme has created a detailed framework to start addressing these challenges once production is underway.

Consultation and exploration in marketing are the recommended next steps for BANZ as the scientific research is sound and well established.

8 Limitations

This report has been prepared by Beca Ltd solely for the Bioenergy Association of New Zealand. The report has been prepared to provide information on food waste digestate to the Client. The contents of this report may not be used by the Client for any purpose other than in accordance with the stated Scope.

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